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ASSESSING THE VALUE-ADDED BY THE ENVIRONMENTAL TESTING PROCESS WITH THE AID OF PHYSICS/ENGINEERING OF FAILURE AND ENGINEERING ECONOMICS EVALUATIONS

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Abstract

NASA's Code QT Test Effectiveness Program is funding a series of applied research activities focused on utilizing the principles of physics and engineering of failure and those of engineering economics to assess and improve the value-added by the various validation and verification activities to organizations. A methodology developed and reported previously, the Physics and Engineering of Failure, has been applied to various elements of aerospace products and commercial electronics testing programs. This paper presents 1) some of the metrics developed to date, 2) effectiveness assessments for selected verification and validation activities and 3) outlines future work within this arena, This paper will also address data levels and what information can be reliably extracted from various qualit ies of data.

Keywords
Metrics, Screening, Effectiveness, Reliability, Testing, Physics of Failure, Failure Modes, Engineering Economics, Verification and Validation, Data Quality, data Levels.

Introduction

As NASA continues its transition to Better, Faster and Cheaper flight projects, there is a need to reduce the extent of verification and validation (e.g. testing) while simultaneously increasing the overall effectiveness of the design, build and test process. This can only be achieved through effective implementation of an optimal subset of the previous verification and validation activities. Everyone knows intuitively that there is "fat" to trim; what remains uncertain is where the "fat" is located. What is needed is a collection of metrics and a process for utilizing the results: this paper describes the former while the latter process has been previously reported[1,2,3]. Utilizing a "Physics and Engineering of Failure" approach[4] one can begin to develop the necessary tools to evaluate the effectiveness and efficacy of an individual, or a collection of, failure mode prevention, precipitation or detection process steps.

A chart used at JPL to convey the interplay between the various verification and validation activities, the design and the implementation decisions is provided in Figure 1. This chart depicts the various potential failure modes as solid arrows falling from a failure modes box at the top of the chart. Below these failure modes is a collection of boxes representing the various PACTS* which could be done to prevent or detect these failure modes prior to their occurrence in the box at the bottom of the chart: Mission Success? The goal of combining these boxes is to maximize the overall effectiveness of the combination of PACTS implemented on a particular flight project or element thereof. The chart also illustrates several points worth mentioning:

1) Each individual box on the chart (a PACT, such as: Assembly Vibration Testing) has some collection of failure modes which it can detect with some effectiveness. "Escapes" or detection efficiencies less than 100°/0 arc denoted with a dashed line and may or may not be detected by a subsequent box (PACT). Dashed lines arc also used to denote test induced failures (i.e. operator error, support equipment fault, etc.).

2) There can be failure modes like the onc to the right of the figure which remain undetected until flight. These arc in general very serious (depending on the impact) and one goal of a good reliability program is to reduce the likelihood of occurrence of these to a minimum while also minimizing the impact of a possible occurrence, consistent with project risk policy. How to implement the metrics described in this paper, weighted by a number of project factors is the subject of References 1 and 2.

3) The general uneasiness towards change and reduction in the number of PACTS can be understood by examining the figure. In some cases, there may be 5 or 6 "layers of boxes" (opportunities to prevent or detect a failure mode), while in other cases there is just onc

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" PACTS= Preventative measures, Analyses, process Controls, and Tests (i.e. everything which can be done to detect or prevent the presence of failure modes) chance to keep a failure mode from occurring in flight. Without good metrics and a systems perspective, the lack of knowledge regarding which particular activity (e.g. System Cold Start Test) is just another redundant PACT or the only chance to preclude a flight failure, will invariably lead to a reluctance to change.

4) For different mission characteristics and technologies, the Screening Diagram (Figure 1) may have different distributions, types, likelihoods, and impacts of the various failure modes. Thus, the optimal combination of PACTS must be tailored for each specific project, working from a minimal group of "essential" PACTS.

Physics of Failure

The big advantage of a "root cause" or Physics and Engineering of Failure approach is that, at the "root cause" level, most failure modes can be effectively prevented or detected by using models, data, test results, etc. Later projects will be able to directly utilize this information for their particular weighted set of failure modes, rather than relying on the "take it exactly as is or discard the data" approach associated with only be understanding at the box-level of qualification. JPL has developed a variety of tools, in such applications as Excel®, Fox Pro® and DOORS® which facilitate the process for prioritizing the project requirements, weighting the various failure modes, and determining the optimal combination of PACTS. While the population of these tools is incomplete, preliminary implementations of the process have been successful.

Reference 4 provides a chart which is useful in understanding the information required and the process for obtaining this information in the development of metrics. This chart is repeated here as Figure 2. It can be seen that at any step, one can utilize existing metrics evaluations, develop a program to obtain ncw metrics and metrics evaluations (via new data) or "take your chances" based on incomplete data. This process is an integral part of the JPL/NASA Test Effectiveness Program[†]

[†] Program funded by NASA HQ Code QT, Payloads and Aeronautics Division, with Mr. Stephen Wander as the NASA HQ sponsor. This is a joint program with the Goddard Space Flight Center, Greenbelt, MD. There are a number of Working Groups and Workshops implemented with industry and government team members - for more information contact either of the two authors.

The goal of this paper is to illustrate the process for establishing, evaluating and using the results of metrics evaluations for various PACTS. The focus of the NASA Test Effectiveness Program is primarily on testing, but the interplay between testing and the other PACTS (PACs actually) must be included in an overall optimization process.

Metrics Development, Evaluation and Utilization

Metrics come in a wide variety of shapes and sizes. They include: 1) programmatic metrics which focus on schedule, resources and milestone achievement, 2) performance metrics which focus on the degree to which various functional and performance requirements where met, 3) effect iveness metrics which focus on how technically- and resource-effective various activities arc/were.

It is these latter types of metrics and metrics evaluations which this paper addresses. There arc also two components to metrics implementation: 1) dctining the metrics (i.e. defining what to measure and 2) performing the measurements (i.e. evaluating the metric). Metrics can also generated at a variety of levels with varying utilities. By levels wc refer to a number of things including hardware level (e.g. systems versus component), and level of data definition and quality (e.g. workmanship defect discovered during vibration testing versus voided bondline failure detected during exposure to 1 kHz excitation).

The process of evaluating these metrics requires careful application of hypotheses testing, statistical principles with significant attention paid to assumptions and "aliased" factors (e.g. technology differences resulting in different distributions of defects detected during different tests on different projects). In the context of this paper, factors arc considered to be aliased when the individual effect(s) and/or contribution(s) of one factor can't be separately identified (from the contribution made by other factors) based on information included in the evaluation, Each factor within this group is considered to be aliased (i.e. non differentiable) with all the other factors within this group. Note the contrast between aliased factors and synergistic factors (i.e. both factors must be present in order for the effect to occur).

By recognizing aliased and synergistic factors one can significantly expand the utility of a given metrics evaluation. The process for understanding the role of these aliased factors involves performing lower level metrics evaluations and then integrating these up to the desired level. In genera], this process of arriving at a given metric evaluation based on the integration of" lower level metrics evaluations, greatly improves the quality and applicability of metrics evaluations arrived at.

Metrics evaluations which can be characterized as being "at the program level" are referred to as Level 1. Examples of Level 1 metrics would be: 1) the relative effectiveness of two different reliability programs on similar hardware, 2) the changes in defect distribution duc to different spacecraft generations, 3) the effectiveness of onc environmental test program versus another (e.g. based on Mil-Std 1540C versus one based Mil-Std-1540B), or 4) the effectiveness of onc parts dcrating program versus another (e.g. based on Mil-Std 975 versus a particular organization's in-house dcrating standard). The advantage of Level 1 metrics is that they are relatively easy to measure, the disadvantage is that there are significant challenges in applying the results to current or future missions. Some significant aliased factors are: technology evolution, materials and process changes, and planned versus actual PACT implementation.

Level 2 metrics are typically characterized as being at the system level. Two examples arc the efficacy of deferring unit level testing to the system level or the relative effectiveness of a single test type performed at different levels of hardware integration.

Level 3 metrics are typically characterized as being "at the subsystem or unit level" or as enabling evaluations of the efficacy of specific PACTS. Such as: 1) the relative effectiveness of one type of test versus another, or 2) the thoroughness of Worst Case electrical analysis versus anomalies detected during bench-top testing, Examples of parameters aliased at this level include: 1) the thoroughness of the functional testing, 2) selected test parameters and their values (e.g. performing cold starts during a thermal test).

Level 4 metrics arc typically associated with assessing the effectiveness of various PACT parameter types within a given test. For example, how effective is: 1) a cold level versus a hot level or 2) ramp rate versus cold starts during a thermal test. Another example would be how effective are the Mil Std 975H derating requirements for CMOS IC devices versus no dcrating on a low cost commercial electronics product? Typically aliased at this level are the influence of the particular values used for the PACT parameter settings.

Level 5 metrics typically enable the assessment of the of effectiveness of the specific levels selected for the PACT parameters which make up a specific test. An example of this would be: the effectiveness using 3 dB verses 6 dB of margin to detect workmanship defects during a random vibration test. Another example would be: how is the effectiveness of a thermal test affected by the selection of a vacuum pressure setting verses an ambient pressure setting for testing of space flight hardware.

Effectiveness Assessments

Below arc presented several case studies. Each case study first presents some background material. This is followed by a discussion of the metric(s) which have been selected. Next is a description of the metric evaluation process and results. Each case study ends with a discussion regarding utility of the evaluated metric(s).

1. Level 3 Case Study (Escapes/Functional Test Study)[5]

A study was performed to identify the nature of the problcm/failures (PF's) which occurred during system level thermal testing. It identified: escapes from thermal testing performed at lower levels and integration issues which could only be tested at the higher level of integration. It was formulated to document the effectiveness of the functional tests (i.e. electrical tests) executed during the environmental test program. JPL's problem/failure reporting (PFR) database was used as the data source. PFR's were considered relevant to this study if a failure was reported on hardware which had undergone a lower level environmental test previously and if there were sufficient detailed data for further study. The level 3 metrics that were evaluated were: 1) percent of PF's which were escapes from lower level testing, 2) the percentage which were PF's duc to level of integration issues. The level 4 metrics which were evaluated were: the percentage of escapes that were due to potentially deficient functional testing (at the lower level) and 2) potentially ineffective corrective actions.

Level 3 *Metric Evaluation: Escapes:* Sixty five percent of the problems that were found during system/subsystem level thermal testing could/should have been eliminated prior to reaching this level of integration (see Figure 3). Corollary: Thirty five percent were PF's which could only be precipitated/detected by performing the test at this level of integration.

Utility: Two illustrations of the utility of this level 3 escapes met ric (and its corollary) are that it can be used to: 1) assess the need for failure mode detection redundancy between these two PACT's, or 2) to assess the cost effectiveness of deferring lower level testing to the higher level. This is discussed below in the Deferred Risk Case Study.

Two Level 4 metric evaluations resulting from this study were: 1) that 40°/0 of the relevant PF's were the result of potentially ineffective function tests at the lower level and 2) 25°/0 of the PF's that occurred during high level thermal testing were the result of potentially ineffective corrective actions taken on problems that had been detected at the lower level of test.

Utility:
The level 4 metric on the impact of the functional testing (performed as part of the unit level thermal test) is one of the dominate factors (PACT parameters) in determining the overall effectiveness of the test. The level 4 metric evaluation regarding the percentage of PF's which are a result of ineffective corrective action suggests that this is an area where process improvements maybe possible.

2. Level 3 Case Study (Deferred Risk Study)
As another example of developing and applying metrics, a brief metrics evaluation was done for a JPL project to evaluate the impact (or potential benefit) of deferring all unit level testing to the system level and increasing the resources allocated to the system test by a corresponding amount. The primary motivation behind this project request was a desire to reduce the overall project schedule duration and simultaneously increase the effectiveness of system testing. This "deferred risk" study is informative because the process used illustrates 1) utilization of lower level metrics and 2) one approach to addressing failures.

To perform the evaluation, a simple model was used in which the failure modes, or latent defects, arc divided into two categories: FM = failure modes either assembly or system testing would have found and FMsys = failure modes only system testing would find. These failure rnodcs are then found (or not) and then fixed (or not). Failure modes not fixed are those for which fixes turned out to be inadequate. Some assumptions made were:

1. FM and FMsys arc hardware type independent
2. Systcm testing -is capable of finding any failure which would have occurred in assembly level testing.
3. All assembly test costs the same (i.e. arc independent of hardware type).
4. Fixes at each level of assembly cost the same
5. Effectiveness of system testing increases in proportion to additional resources allocated to it.
6. Equal failure mode screening effectiveness at the system and assembly level.

Assumptions 1 through 6 define the factors which were aliased in this analysis. Several of these assumptions (e.g. 2 and 5) clearly crr on the side of the "system test only" answer. Since the answer turned out to be the opposite: do both assembly and system testing, these assumptions are termed *a fortiori*.

Level 2 Metric Evaluation: Utilizing the results of the "Escape" study above and typical JPL values for costs, etc. the result depended to first order on only onc parameter, and to second order on two parameters. The most critical parameter was defined as β where 1: $\beta : \beta^2$ is a generalization of the 1:10:100 rule (fixes cost 10X as much at the next higher level of assembly). The secondary parameters were the nominal cost of the system test and the probability of "escapes" from assembly-level corrective actions. The break-even point between system only testing versus performing both system and unit level testing was found to depend very weakly on the secondary parameters (changing them by 5X produced <10% change in the outcome) and only occurred for values of β below 2.0.

Utility: The result indicates that for the system-level-only approach to make sense onc should have the hardware so modular that fixes at the system level cost only 2X what they would have cost at the assembly level. It also identified for the project that the most significant pay-off to reduce system test costs would be to improve the modularity of the design.

3. Level 3 & 4 Case Study (NCMS ESS 2000)
A collaborative project was organized and managed by the National Center for Manufacturing Sciences (NCMS)[6] to study the efficacy of current and emerging screening technologies for environmental stress screening. Six organizations participated in the project. They were: The Aerospace Corporation, Hamilton Standard Division of United Technologies Corporation, Jet Propulsion Laboratory, Luccnt, Storage Technology and Texas Instruments Defense Systems & Electronics. The current technologies studied were Highly Accelerated Stress Screening (HASS) and Military Environmental Stress Screening (Mil-ESS). Emerging technologies considered were Thermography and Liquid Environmental Stress Screening (LESS). An experiment was designed and ran which yielded statically significant data for the HASS and LESS technologies. Each PACT was divided into a number of test steps. Each test step corresponded to a set of

environmental stresses. A functional test was run during each test step and any failures which occurred during a test step was recorded for later analysis. A physics of failure based evaluation method call Value Added Screening Effectiveness (VASE) was developed and used to assess the results of the experiment. Reference 7 documents the overall project processes and findings.

Level 3 & 4 *Metrics:* The relevant level 3 metric selected was the cost to detect a defect using each type of screen. The Level 4 metric selected was the cost per defect detected for each PACT parameter[‡].

Level 3 *Metric Evaluation:* Evaluation of the level 3 metrics involved a relatively straightforward process of assessing the statistical significance of the number of defects detected by each PACT and then dividing by the cost associated [§] with performing each PACT on the test samples. The cost per defect detected was determined to be $200 for HASS and $215 for LESS. These Level 3 metrics evaluations (i.e. overall cost to detect a defect) were not considered to be significantly different. This Level 3 analysis was enabled by the lower level metrics evaluation discussed below.

Level 4 *Metrics Evaluation:* A process was employed to evaluated the efficacy of the PACT parameter types (i.e. Level 4 evaluation) for the HASS testing. The metrics evaluation process that was followed was: 1) assume an operating, high level hypotheses which could be easily tested, 2) evaluate this hypotheses via performing a lower level analysis of the data and 3) re-testing the hypotheses until the lower level data analysis validated the hypotheses. Once a valid hypotheses was found, costs were assigned to each control parameter via an engineering economics analysis. An example of this process is presented below.

The initial hypotheses (easiest for evaluating a metric) was that numerology (i.e. all failures count equally) could be used in determining the number of defects within the test sample. The metrics evaluation process, using this initial hypotheses, would have been relatively easy to perform. However, further analysis indicated that not all failures were attributable to stress screening. For example, a significant number of the test articles failures were detected by every functional test step even if performed prior to stress screening. Other examples involve counting precipitated failures after their initial occurrence, as in the case of most vibration failures. Therefore, performing metrics evaluations based on this initial hypothesis would have resulted in “bad” metrics.

Two conclusions resulting from using such “bad” metrics evaluat ions would have been that: 1) many more temperature transition cycles would be needed to remove the infant mortality failures and 2) cold vibration is more effective than hot vibration for this hardware design and implementation. The lower level analysis which was performed to test the initial hypotheses, suggested that only the initial failure should be counted and that it might be assigned to the particular stress which was Occurnng at the time of the failure. This ncw hypothesis was tested via a signature analysis (i.e. a study of every failure occurrence). The signature analysis involved performing a manual review of approximately 10,000 records. The signature analysis processes was validated by the consistency of the results of its application (i.e. clear supportable determinations of the stress(es) responsible for the precipitation/detection of each failure). Therefore, the final hypotheses was that the precipitation/detection stress(es) could be determined from this data and that the signature analysis technique was an appropriate tool to use for this purpose. The details of this analysis will be presented in a later paper.

The Costs arrived at from the Level 3 metrics evaluations were distributed according to the amount of time required to create each stress. The sanity of this hypothesis was tested by exercising the cost model. It was determined that this hypothesis was reasonable although it tended to underassess the temperature transition stress at the expense of the others. The resulting level 4 metrics evaluations are shown in Figure 3.

Utility: These level 4 metrics evaluations provide clear guidance for optimizing this PACT (HASS) in such a way as to reduce key costs by 66% while increasing its overall screening strength by emphasizing the value added portions of the screen.

Illustration of Aliased factors: While the LESS testing involved one fewer PACT parameter type (i.e. no vibration), the effects of the individual stresses could not be resolved as finely as in the HASS test. The net effect was that for the

[‡] In the case of the HASS test, the PACT parameters were: hot and cold exposure, hot and cold dwell, ramp up and down rate, vibration hot, vibration hot and cold, voltage margin hot and cold and thermal cycling, For the LESS test they were the same minus vibration.

[§] An engineering economics (spreadsheet model) was developed to aid in process of assessing the cost associated with performing each PACT. See Reference 7 for the details of the cost model.

LESS testing, only five distinct stresses (hot level, cold level, in air and high voltage testing and hot low voltage) could be resolved from the data, compared to 13 for HASS. In other words, the LESS PACT parameter types of: transition cycles, hot and cold dwell times, cold voltage margining and hot high voltage margining were all aliascd.

Other Utilities ofMetrics Evaluation Hypotheses

Even though there were no clear cut winners between LESS and HASS, choices can still be made on the basis of the probability of making the best (i.e. most cost effective) choice. Figure 5 (from Reference 7) shows that if you chose to do LESS instead of HASS, you would have a higher probability of having made the best choice for part/die related failure mode categories. Conversely, if you chose to perform HASS, you have a higher probability of having made the best choice for solder joint related failure mode categories. When viewing the choices this way, you will be able to make the right choice simply by knowing about the "escapcs" from your internal processes weighted by their impact on product integrity.

Additional case studies, environmental test cffcctivcncss analyses and other related publications, (Refcrcnces [8&9]) arc available (which provide mctric evaluations at a variety of levels) but were not presented here for simplicity.

Summary/Conclusions and Future Work

All of these evaluated metrics could also be used to formulate hypotheses, which after evaluation, would either extent the general validity of an evaluated metric or further dcfine it's limit of applicability. Examples of hypotheses which could be formulated for evaluation based on the first evaluated metric would be the percentage of PF's which arc not likely to be detected by lower level of testing of other types: 1) unit lcvel vibration versus systcm/sub systcm level, 2) board verses unit level thermal testing, etc. It could also be used to suggest hypotheses regarding particular aliascd conditions/effects, such as, the PF's that may have been dctcctcd and eliminated between these two tests, etc. Many of the conditions which would determine the validity/limits of further applicability can be evaluated relatively easily. Moreover, once various metrics have been established and evaluated, the routine PF evaluation process could bc modified to capture and automatically analyze the data for these metric evaluations, thereby automatically capturing any shifts in these evaluations.

The metrics generation related plans for future work on JPL's Test Effectivcncss and Flight Pcrformancc Assessment applied research tasks include:

- Continue to develop and evaluate relevant metrics as needed by customers (JPL projects, other NASA Centers, Industry partners, etc.) and as appropriate data is located.
- Work to incorporate existing metrics and metrics evaluations into JPL (and others) problcm failure closure process so that this metrics can be expanded and/or refined.
- Form ncw collaborative projects to expand the data available for metrics and metrics evaluations so that waterfall process charts can be built.
- Utilizc old and/or ncw data to remove aliases which are currently associated with existing metrics evaluations, such as hardware and manufacturing technology effects.
- Support the National Center for Manufacturing Scicnccs in its effort to form a follow-on to the NCMS ESS 2000 project. This ncw project will assess the effectiveness of other PACT's involved with electronics products.
- Use existing metrics evaluations to identify ncw PACT's which have the potential to significantly reduce costs and improve cffcctivcncss via the removal of layers of redundancy or identifying potential ncw "out-of-the box" solutions.

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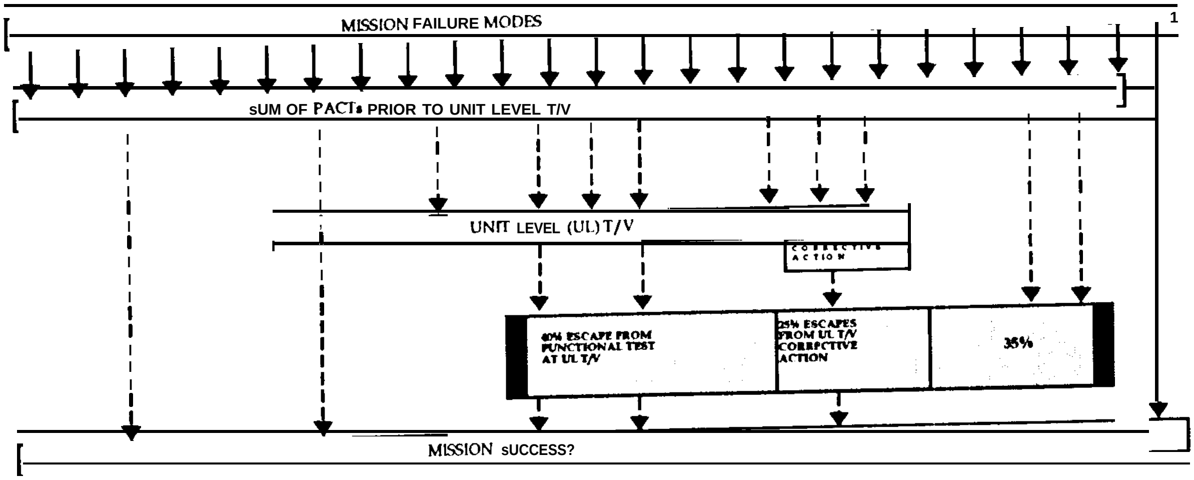

Figure 3 Graphical illustration of metrics evaluations from a study of problem/failures occurring during system level thermal vacuum testing

HASS STRESSES PLUS FUNCTIONAL FAILURES, I.e. Dead-On-Arrivals	TIMING	FUNCTIONAL FAILURE/WRONG OUTPUT	UNKOWN	SHORT	STUCK B—(CRACKED DIE)	NO DEFECT FOUND	INSUFICIENT SOLDER	COLD SOLDER JOINT	SOLDER BALL	SOLDER BRIDGE	SOLDER WETTING	FLUX CLEANING PROCESS FAILURE	COPLANARITY	HANDLING	ICT TEST SKIPPED	INTERRUPT	PARAMETER DRIFT	OTHERS	TOTAL FAILURES DETECTED BY KNOB	Relative Cost/Defects found (by Screening Stress)
	FAILURE MODES/MECHANISMS																		TOTALS	DEFECT COSTS
FUNCTIONAL TEST (DOA)	3	—	—	2	1	—	—	1	1	—	—	9	1	4	1	1			24	$17
COLD LEVEL	2	4	2	—	—	1	1	2	—	—	—	—	—	—			—		12	$70
COLD/LOW VOLTAGE	3	2	1	—	—	—	—	—	—	—	—	—	—	—			—		6	$70
VIBRATION OR HOT/VIRBRATION	—	1	—	1	—	—	—	—	—	1	2	—	—	—			1		6	$559
HOT LEVEL OR RAMP RATE	1	2	—	—	1	1	—	—	—	—	—	—	—	—			—		5	$335
COLD/HIGH VOLTAGE	1	2	—	—	—	—	—	—	—	—	—	—	—	—			—		3	$140
HOT LEVEL	2	—	—	—	—	—	—	—	—	—	—	—	—	—			—		2	$419
HOT/HIGH VOLTAGE	—	—	2	—	—	—	—	—	—	—	—	—	—	—			—		2	$210
COLD/NEGATIVE RAMP	1	—	1	—	—	—	—	—	—	—	—	—	—	—			—		2	$210
HOT/LOW VOLTAGE	—	—	2	—	—	—	—	—	—	—	—	—	—	—			—		2	$210
RAMP RATE (?)	—	—	1	—	—	—	—	—	—	—	—	—	—	—			—		1	$419
HOT DWELL OR HOT AFTER VIB	—	—	—	—	—	1	—	—	—	—	—	—	—	—			—		1	$839
MULTIPLE THERMAL CYCLES	—	—	—	—	—	1	—	—	—	—	—	—	—	—			—		1	$5,032
TOTAL FM's FOUND BY ALL KNOBS	13	11	9	3	2	4	1	3	1	1	2	9	1	4	1	1	1	0	67	$200

Figure 4 Level 4 metrics evaluation for the efficacy of the various control parameters used in performing HASS

CONFIDENCE LEVEL ESTIMATE	MING	FUNCTIONAL FAILURE/WRONG OUTPUT	SHORT	STUCK BIT (Cracked Die)	SOLDER DEFECTS (REFLOW + INSUFFICIENT SOLDER + COLD JOINT + BRIDGE + WETTING)	FAILURE NOT REPRODUCIBLE OR UNKNOWN (?)	PARAMETER DRIFT	OPEN TRACE INSIDE BOARD	WIRE SHORTED	OVERALL INCLUDING NO DEFECT FOUND & UNKNOWN	OVERALL EXCLUDING NO DEFECT FOUND & UNKNOWN	DEFECT COSTS ($/defect detected)
Ho= HASS is equal or better than LESS	90%	84%	82%		82%		74%		74%	32%	82%	$200
Ho= LESS is equal or better than HASS				99%		98%		94%		68%	18%	$216

Figure 5 Comparison **matrix for HASS and** LESS **processes (by tall pole failure modes)**